Chapter 13

Cassava Residues Could Provide Sustainable Bioenergy for Cassava Producing Nations

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Additional information is available at the end of the chapter

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Abstract

Many cassava producing nations lack suitable energy availability and sufficiency. Just 10% of the population in Haiti receive power from the national electric grid. The proportion is 7% for Mozambique. In both countries, deforestation is extensive due to dependence on wood and charcoal for 70 and 85% of energy requirement respectively. In the case of Ghana, although biomass accounts for 64% of national energy supply, the dependence on primary biomass energy sources like wood and charcoal has led to increased loss of biodiversity, soil erosion and health problems. Prospects for the use of cassava peeling residues as a source of biomethane to mitigate these constraints have received little attention. In this chapter, the advantages and benefits of biomass energy, along with the potential for cassava as a feedstock and rationale for anaerobic digestion are highlighted. Depending on the quantity of cassava root processed by individual countries, the energy recovered from cassava peeling residues could satisfy up to 100% of national energy requirements.

Keywords: biomass, cassava residues, anaerobic digestion, biomethane, renewable energy

1. Introduction

In July 2015, world population was estimated at over 7.3 × 10^9 persons and will exceed 9.7 × 10^9 persons in July 2050 [1]. At the same time, planet earth's capacity to sustain life is diminishing. Issues such as land use conflicts, rural poverty, food insecurity, energy insecurity and environmental pollution are posing serious threats to humanity. Global energy supply is dependent on fossil fuels, which account for over 78% of final energy consumption [2]. Fossil fuels are depleting non-renewables, and their use exacerbates anthropogenic forcing of environmental perturbations including carbon dioxide and other greenhouse gas emissions, acid rain, biodiversity and ozone layer depletions. Advancing global energy supply system toward renewable bioenergy could constrain these adverse impacts.

The poor economic development and progress in developing countries have been attributed in part to inadequate suitable energy supply. Mainly developing countries produce cassava. However, most of the production occurs in rural areas where fuel/electricity availability is limited. In Mozambique for instance, only 7% of households (1% in rural areas) has access to electricity [3], and 85% of total energy consumed comes from firewood and charcoal [4]. In Haiti, 10% of the population receive power from the national electric grid while wood and charcoal account for 70% of the nation's energy use [5, 6]. These circumstances have led to extensive deforestation and soil erosion in both countries; with just 1.5% of land forested in Haiti [6], and 219,000 hectares of land deforested per year in Mozambique [4]. In the case of Ghana, although biomass accounts for 64% of national energy supply, the dependence on primary biomass energy sources like wood and charcoal has led to increased deforestation, land degradation, loss of biodiversity, soil erosion, and health problems [7]. Creative use of cassava as an energy crop would help to mitigate environmental degradation and energy paucity issues, as well as minimize the health problems associated with the combustion of firewood and charcoal in cassava producing nations.

Biomass energy should be of interest to developing and developed countries. This is because biomass alleviates reliance on limited fossil fuel sources, creates employment, and contributes to economic development and revitalization of rural communities. Biomass is a clean energy source that dramatically improves the environment by generating far less air emissions than fossil fuels, reduces the amount of waste sent to landfills, and decreases reliance on chemical fertilizer. Moreover, biomass energy is renewable and therefore sustainable. Renewable energy supplied 19% of global energy consumption in 2012 and in 2013, accounted for more than 56% of net additions to global power capacity with about 6.5 million people employed [2]. In 2015, renewable energy sales in Europe was 150 billion euros (≈ US$ 178 billion) [8].

These trends demonstrate the growing utility, benefits and advantages of renewable energy of which biomass energy is a major component. However, the use of edible biomass (food crops such as sugarcane, corn (maize), soybean, palm oil, etc.) for biofuel (bioethanol, biodiesel, etc.) production has raised ethical concerns about competition and diversion of land and food to fuel production. Perhaps a reasonable alternative is biofuel production from biomass originating from nonfood sources such as, agricultural residues, food processing residues, lignocelluloses, and microalgae. Nonfood cassava peeling residues (CPR) could come to the rescue.

2. Potential of cassava as feedstock for bioenergy production

Cassava (*Manihot esculenta Crantz*) is a mostly vegetatively propagated perennial root crop that grows well in tropical climates. Nevertheless, the roots (main reason for growing cassava) are very perishable once taken from the soil and go to waste unless processed in some way soon after harvest. Most processing requires removal of peels (cortex and periderm), head, and tail ends. These components usually discarded as waste, engender environmental

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pollution. In this chapter, the components are referred to collectively as cassava peeling residues (CPR), and instead of being discarded as waste, would be put to bioenergy production function. The CPR is generated during production of numerous cassava root based food products like akpakpuru, attieke, casabe, chickwangue, farina (farinha de mandioca), fufu, fuku, gaplek, gari, ijapu, konkonte, lafun, landang, peujeum, and thundam [9–22]. Because more than 65% of global annual cassava output is processed for human consumption, enormous quantity of CPR is generated. This nonfood organic matter is potential good feedstock for anaerobic digestion (AD) processes that generate bioenergy.

There are numerous other reasons for the attraction of cassava crop as source of food and bioenergy.

- Cassava provides economic and subsistence value for 800–1000 million people in more than 90 countries including Angola, Barbados, Brazil, Cambodia, China, Cook Islands, Democratic Republic of Congo, Dominica, Ghana, Haiti, India, Indonesia, Lao Peoples Democratic Republic, Mozambique, Nigeria, Suriname, Thailand, Uganda, United Republic of Tanzania, and Vietnam [23–25].

- It is the fourth most important food crop in developing nations. Cassava is also world's third largest source of food carbohydrates and the top food energy supplier for tropical and subtropical regions. About 30% of all calories consumed in Mozambique come from cassava [26]. In Zaire, cassava roots provide 60% of the daily caloric intake, while 20% of protein come from cassava leaves [27]. In addition, Cassava can be biofortified with vitamin A, iron and zinc to eliminate hidden hunger and improve the nutritional status of vulnerable groups.

- Cassava presents numerous agro-climatic advantages and benefits as well. First, it has high biological efficiency as the edible root portion lies underground and does not require support from stems and branches. It is easily cultivated by stem cuttings for multiplication and planting purposes, and requires minimum agricultural inputs (fertilizers, pesticides, etc.). With the possible exception of sugarcane, cassava's productivity in terms of calories per unit land area per unit of time is significantly higher than that of other staple food crops; and its production requires energy input that constitutes just 5–6% of the energy output of the entire cassava biomass [28].

- Cassava can be planted most time of the year and is available all year long with more than 2 years harvest window. Cassava is adaptable to various farming systems. It can be intercropped with beans, yams, and other annual crops. It is tolerant of various climatic conditions (e.g., high drought; temperature: 8–33°C; rainfall: 500–6000 mm per annum; relative humidity: 15–90%; and elevation: sea level–2500 m). Cassava is also productive on soils with pH of 3–9.5. It can thus be cultivated on marginal lands where other crops such as corn, wheat, rice and sugarcane cannot be grown well [29, 30]. Cassava has high efficiency of photosynthetic CO_2 assimilation. The photosynthetic rate of cassava is 40–50 μmol CO_2 m^{-2} s^{-1} under high solar radiation. That of rice is around 20 μmol CO_2 m^{-2} s^{-1} [31].

- Cassava root is endowed with high starch content of excellent functional and structural qualities. The cassava starch can be transformed into products with huge industrial applications and is of major economic importance in Brazil, India, Indonesia, Philippines, China, Thailand, South East Asia, and in the tropical regions of the world.

- Cassava is a major ingredient for livestock feeds.
- Cassava is important in the provision of bioenergy such as bioethanol and biogas. For instance, the yield of bioethanol from cassava (6000 kg/ha) is higher than that of sugarcane (4900 kg/ha), carrot (4500 kg/ha), sweet sorghum (2800 kg/ha), Rice (2250 kg/ha), Maize (2050 kg/ha), and wheat (1560 kg/ha) [32]. A feasibility case study in Kenya using biogas engine for backup power generation showed ample savings over the use of diesel engine. Biogas engine saved 17 tons of carbon dioxide emissions, 18% reduction in net present cost, 20% reduction in levelized cost of electricity, and 30% reduction in capital cost [33].

Energy recycling from biomass residues and wastes is increasingly attractive because the sustainability of analyzed feedstock favors biomass waste flows over dedicatedly cultivated

S/N	Feed stock	BFP yield	BFP units	References
1.	Cassava peeling residue	377	L CH_4/(kg VS)	[47]
2.	Cassava peeling residue	180–310	L CH_4/(kg VS)	[10]
3.	Cassava peeling residue	280	L CH_4/(kg VS)	[48]
4.	Cassava peeling residue	87.1	L biogas/(Total mass of slurry)	[49]
5.	Cassava peeling residue	68.7	L biogas/(Total mass of slurry)	[50]
6.	Cassava starch extraction wastewater	360	L biogas/(kg COD removed)	[51]
7.	Cassava starch extraction wastewater	130–325	L biogas/(kg dry matter)	[52]
8.	Cassava starch extraction wastewater	134–316	L CH_4/(kg VSS Day)	[53]
9.	Cassava starch extraction wastewater	140	Nm^3 per Mg dry mass of COD	[54]
10.	Cassava starch extraction wastewater	11.3	L CH_4/(kg VSS Day)	[55]
11.	Cassava starch extraction wastewater	0.52–3.70	L biogas/(L wastewater Day)	[51]
12.	Cassava starch extraction wastewater	0.40–0.55	L CH_4/(L effluent Day)	[53]
13.	Cassava stillage	215–380	L CH_4/(kg VS)	[56]
14.	Cassava stillage	132–259	L CH_4/(kg VS)	[57]
15.	Cassava stillage	249	L CH_4/(kg VS)	[58]
16.	Cassava stillage	158–248	L CH_4/(kg VS)	[59]
17.	Cassava stillage	220–230	L CH_4/(kg COD added)	[60]
18.	Cassava tubers	660	L biogas/(kg VS)	[48]
19.	Cassava tubers	475–510	L biogas/(kg VS)	[61]
20.	Cassava stem residues after starch extraction	153	Nm^3 per Mg dry mass of stem residues	[54]
21.	Cassava flour and meal industry effluent	14.5	L biogas/Day	[62]

Table 1. Biofuel potentials (BFP) of cassava feedstocks.

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energy crops [34]. Therefore, utilization of nonfood cassava processing residues such as CPR in biomethane production via the anaerobic digestion technology is prudent and beneficial. Nevertheless, in order to properly assess and quantify the value and contribution of CPR to the energy mix of cassava producing nations, establishment of Biofuel Potential (BFP) of CPR is necessary. Relatively very few studies have been published on biomethane production from cassava feedstocks. Most of the studies utilized cassava starch extraction wastewater. Other cassava feedstocks used were stillage (wastewater) from cassava ethanol production; cassava stem residue; whole cassava root; effluent from cassava flour and meal industry; and cassava peeling residue (CPR). However, CPR constitutes about 19% fresh weight of the root and is perhaps the most abundant residue from cassava root processing. It is easy to generate and does not require water usage. Therefore, analyses of energy impact of cassava crop in this chapter will use CPR as the feedstock of choice in renewable biomethane production. **Table 1** summarizes the biofuel potentials of CPR and other cassava feedstocks.

3. Rationale for anaerobic digestion technology

Anaerobic digestion (AD) is a biochemical process that converts organic matter to biogas (a mixture of methane and carbon dioxide). This is achieved through the action of a mixed culture of naturally occurring microorganisms under near oxygen free ambient environmental conditions. The following attributes are among the numerous advantages and benefits of AD technology:

a. Flexible technology; energy efficient; prevents emission of volatile hazardous compounds (air pollution control); biotransformation and biodegradation of xenobiotics; treatment of seasonal effluents (e.g., wastewaters from sugar and fish processing industries); system stability and minimal operational difficulties such as bulking and biomass washout; higher loading rates and concentrations operations, from 20 to 40 kg BOD removed/m^2 per day; reduced mass and volume of waste sludge; high waste stabilization; and Low construction, treatment and maintenance costs are typical examples.

b. AD can accommodate tighter restrictions on sludge disposal site location, air pollution, hazardous waste disposal, odor control, and other environmental regulations.

c. AD is attractive as a means of generating alternative energy such as biogas used for electricity and heat production, and to feed gas networks.

d. Among biofuel systems, AD is a highly energy positive process. AD generates energy as methane; with about 3.53 kWh/(kg COD) produced as biogas while aerobic treatment operations consume 0.5–2.0 kWh/(kg O_2) [35].

e. AD is used to produce hygienic digestate; a good source of soil organic amendment, compost and biofertilizer that can be sold for income generation.

f. AD is a low cost, low technology energy source for developing countries. It can be used to achieve more sustainability and energy justice in society [36, 37].

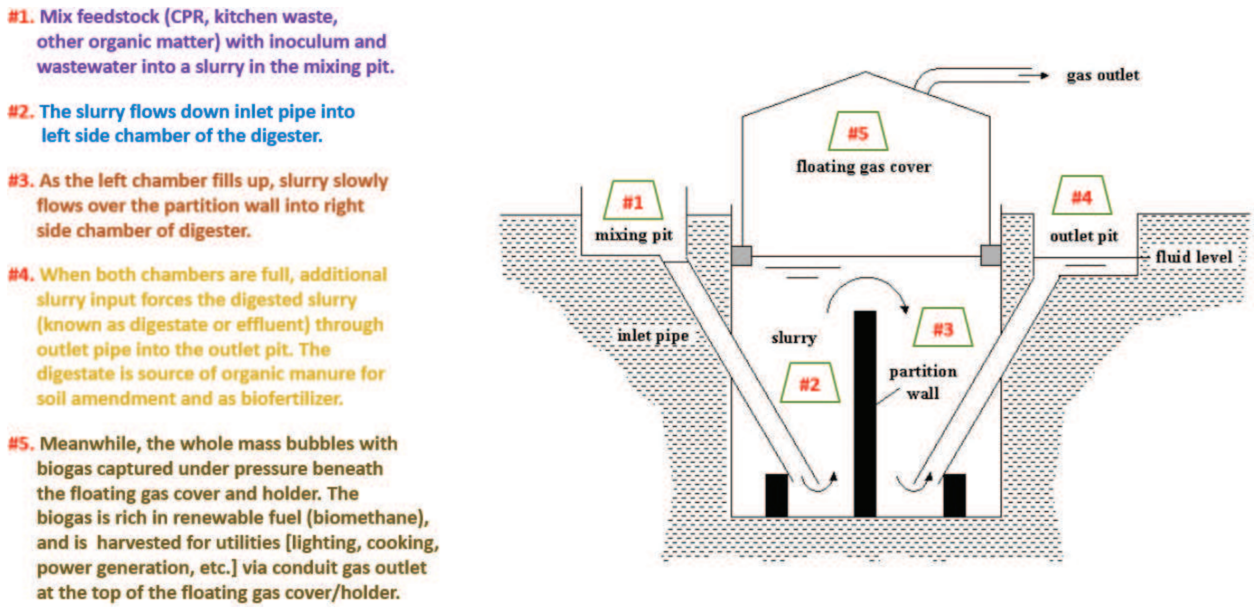

Figure 1. Basic architecture and operating principles of the floating cover anaerobic digester. The sketch to the right was adapted with permission from Ref. [46].

g. In addition, AD is versatile, with commercial equipment in varied types, shapes, sizes and operating modes. These include BIOCEL, Bioferm, GICON and SEBAC (sequential batch anaerobic composting); as well as the ABR (anaerobic baffled reactor), AF (anaerobic filter), CSTR (completely stirred tank reactor), EGSB (expanded granular sludge bed), UASB (upflow anaerobic sludge bed), fixed dome, floating cover, and balloon/tube digesters. **Figure 1** highlights the operating principles of a simple floating cover anaerobic digester.

4. Technical feasibility of anaerobic digestion of CPR

Information obtained from available literature were analyzed to determine critical values relevant to CPR biogasification characteristics. **Tables 2** and **3** summarize estimates and assumptions concluded from the analyses. These data and assumptions were also used to perform the mass balance computations presented in **Figure 2**.

To compute the energy obtained from methane generated by AD of CPR, the following equations were used.

$$T_{me} = M \times HHV \quad (1)$$

$$E_{me} = T_{me} \times \epsilon = M \times HHV \times \epsilon \quad (2)$$

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S/N	CPR mass fraction (%)	References
1.	18	[10]
2.	18	[63]
3.	30	[47]
4.	16	[64]
5.	17	[65]
6.	17	[66]
Mean: ≈ 19		

Table 2. CPR mass fractions of fresh cassava root.

where T_{me} = Thermal energy content of methane (MJ), M = Mass of methane (kg), HHV = Heat of combustion of methane (MJ/kg), E_{me} = Electrical energy equivalent of T_{me} (MWh), ϵ = Conversion efficiency; thermal energy to electrical energy (%), Note: This work used HHV = 55.53 MJ/kg, ϵ = 25% and 3600 MJ = 1 MWh.

Table 4 presents the 2014 cassava output and energy consumption patterns of cassava producing countries. Many of these countries are net energy importers; lacking in local energy capacity and sufficiency. However, in 2014, the global cassava output was over 268 million tonnes. Based on the equations, mass balances and analyses already posited in this chapter,

S/N	Variable of interest	Unit	Value assumed	Explanation/justification	Source/ references
1.	CPR mass fraction of root	(%)	19	Derived from literature data	**Table 2**
2.	CPR moisture content, wet basis	(%)	67	Mean of four replications	[10]
3.	CPR methane capacity	(L CH_4/ (kg VS))	303	Derived from **Table 1**	[10, 47, 48]
4.	Methane obtained from CPR generated by processing 1 tonne (1000 kg) of roots	(kg)	12.55	Derived from 252 L CH_4/(kg VS CPR) = 10.44 kg CH_4	[10]
5.	Proportion of cassava root output processed	(%)	66 & 100	More than two–thirds of total production processed for human food	[67]
6.	Quantity of cassava root output processed	(kg)	Varies per country	Based on 66 and 100% of individual country's 2014 cassava output (see **Table 4**)	[24, 67]

Table 3. Values assumed for variable parameters used in analytical modeling.

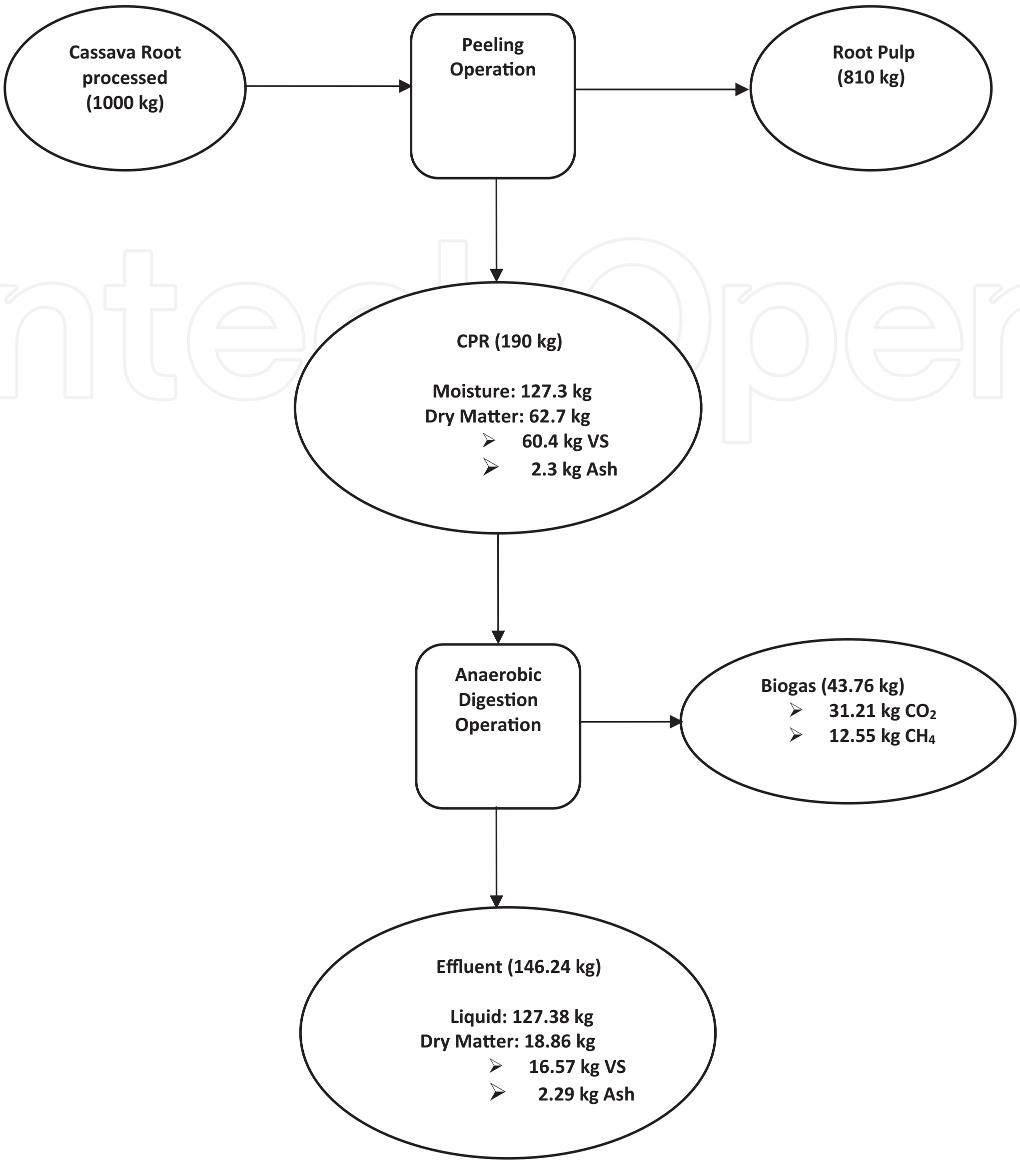

Figure 2. Mass balance for the anaerobic digestion of CPR from 1 tonne (1000 kg) of cassava root for biomethane production.

1 tonne of cassava root yielded 190 kg CPR. This CPR is transformed to 12.55 kg of methane; producing 697 MJ thermal energy or about 174 MJ electrical energy (≈ 0.0484 MWh). Therefore, the 268 million tonnes global cassava root output in 2014 would produce 51 million tonnes of CPR. This quantity of CPR would generate 3363.4 million kg of bio-methane which translates to 186.8×10^9 MJ of thermal energy; equivalent to 46.7×10^9 MJ of electrical energy (≈ 13×10^6 MWh). This is an enormous quantity of energy that could satisfy all the yearly energy needed by Slovenia or Turkmenistan. This energy should be recovered for the benefit and rescue of cassava producing nations. The foregoing analyses were applied to individual cassava producing nations to estimate the energy recoverable from their CPR. The results obtained are also presented in **Table 4**. It could be seen that the ability of recoverable energy from CPR to provide national energy requirement depends on the quantity or proportion of national cassava root output processed.

S/N	Country	2014 Cassava output ($\times 10^9$ kg) [b]	2014 National energy consumption (MW.h/Y) [c]	Energy from CPR if 100% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 100% national cassava output was processed (%)	Energy from CPR if 66% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 66% national cassava output was processed (%)
1.	Nigeria	54.8316	24,000,000	2653301.124	11.05542135	1751178.742	7.296578091
2.	Thailand	30.022052	164,000,000	1452767.096	0.885833595	958826.2835	0.584650173
3.	Indonesia	23.436384	195,000,000	1134086.622	0.581582883	748497.1704	0.383844703
4.	Brazil	23.253514	518,000,000	1125237.542	0.217227325	742656.778	0.143370034
5.	Ghana	16.524	9,200,000	799596.36	8.691264783	527733.5976	5.736234757
6.	Dem. Rep. of Congo	14.683266	9,300,000	710523.2417	7.640034857	468945.3395	5.042423006
7.	Viet Nam	10.209882	125,000,000	494056.19	0.395244952	326077.0854	0.260861668
8.	Cambodia	8.325098	4,100,000	402851.4922	9.825646152	265881.9849	6.48492646
9.	India	8.13943	1,001,191,000	393867.0177	0.039339848	259952.2317	0.0259643
10.	Angola	7.63888	8,100,000	369645.4032	4.563523496	243965.9661	3.011925508
11.	Mozambique	5.304188	12,000,000	256669.6573	2.138913811	169401.9738	1.411683115
12.	Malawi	5.012763	2,100,000	242567.6016	11.55083817	160094.617	7.623553192
13.	United Rep. of Tanzania	4.992759	5,000,000	241599.608	4.83199216	159455.7413	3.189114826
14.	Cameroon	4.917544	6,100,000	237959.9542	3.900982855	157053.5697	2.574648684
15.	China	4.659481	5,919,800,000	225472.2856	0.003808782	148811.7085	0.002513796
16.	Côte d'Ivoire	4.239303	5,800,000	205139.8722	3.536894348	135392.3156	2.33435027
17.	Sierra Leone	4.135064	200,000	200095.747	100.0478735	132063.193	66.0315965
18.	Benin	4.066711	1,000,000	196788.1453	19.67881453	129880.1759	12.98801759
19.	Rwanda	3.159551	500,000	152890.6729	30.57813458	100907.8441	20.18156882

S/N	Country	2014 Cassava output (×10^{9} kg) [b]	2014 National energy consumption (MW.h/Y) [c]	Energy from CPR if 100% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 100% national cassava output was processed (%)	Energy from CPR if 66% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 66% national cassava output was processed (%)
20.	Paraguay	3.06	9,700,000	148073.4	1.526529897	97728.444	1.007509732
21.	Madagascar	2.929743	1,300,000	141770.2638	10.90540491	93568.37409	7.197567238
22.	Uganda	2.812	2,700,000	136072.68	5.039728889	89807.9688	3.326221067
23.	Philippines	2.540254	66,000,000	122922.8911	0.186246805	81129.1081	0.122922891
24.	Burundi	2.242352	400,000	108507.4133	27.12685332	71614.89276	17.90372319
25.	Colombia	2.186207	60,000,000	105790.5567	0.176317595	69821.76744	0.116369612
26.	Lao People's Dem. Rep.	1.629805	3,900,000	78866.26395	2.022211896	52051.73421	1.334659851
27.	Congo	1.334881	900,000	64594.89159	7.177210177	42632.62845	4.736958717
28.	Guinea	1.264078	900,000	61168.73442	6.796526047	40371.36472	4.485707191
29.	Peru	1.195926	39,000,000	57870.85914	0.148386818	38194.76703	0.0979353
30.	Togo	1.153109	1,100,000	55798.94451	5.072631319	36827.30338	3.347936671
31.	Zambia	0.919497	11,000,000	44494.45983	0.404495089	29366.34349	0.266966759
32.	Kenya	0.858461	7,600,000	41540.92779	0.546591155	27417.01234	0.360750162
33.	Centr. Afric. Rep.	0.699764	200,000	33861.57996	16.93078998	22348.64277	11.17432139
34.	Haiti	0.615	400,000	29759.85	7.4399625	19641.501	4.91037525
35.	Liberia	0.534810	300,000	25879.4559	8.6264853	17080.44089	5.693480298
36.	Myanmar	0.485	11,000,000	23469.15	0.213355909	15489.639	0.1408149
37.	Cuba	0.435772	15,000,000	21087.00708	0.140580047	13917.42467	0.092782831
38.	Venezuela (Boli. Rep.)	0.357876	78,000,000	17317.61964	0.022202076	11429.62896	0.01465337

S/N	Country	2014 Cassava output ($\times 10^9$ kg) [b]	2014 National energy consumption (MW.h/Y) [c]	Energy from CPR if 100% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 100% national cassava output was processed (%)	Energy from CPR if 66% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 66% national cassava output was processed (%)
39.	Sri Lanka	0.301548	11,000,000	14591.90772	0.132653707	9630.659095	0.087551446
40.	Senegal	0.257259	3,000,000	12448.76301	0.414958767	8216.183587	0.273872786
41.	Gabon	0.247889	2,100,000	11995.34871	0.571207081	7916.930149	0.376996674
42.	Bolivia (Plu. State of)	0.245808	7,500,000	11894.64912	0.158595322	7850.468419	0.104672912
43.	Zimbabwe	0.235052	8,000,000	11374.16628	0.142177079	7506.949745	0.093836872
44.	Nicaragua	0.231658	4,412,000	11209.93062	0.25407821	7398.554209	0.167691619
45.	Argentina	0.186944	116,000,000	9046.22016	0.007798466	5970.505306	0.005146987
46.	Dominican Republic	0.178327	15,140,000	8629.24353	0.056996325	5695.30073	0.037617574
47.	Costa Rica	0.1755	9,200,000	8492.445	0.092309185	5605.0137	0.060924062
48.	Chad	0.166888	200,000	8075.71032	4.03785516	5329.968811	2.664984406
49.	Papua New Guinea	0.148213	3,000,000	7172.02707	0.239067569	4733.537866	0.157784596
50.	Niger	0.133099	1,200,000	6440.66061	0.536721718	4250.836003	0.354236334
51.	South Sudan	0.126244	694,100	6108.94716	0.880124933	4031.905126	0.580882456
52.	Ecuador	0.111743	21,000,000	5407.24377	0.02574878	3568.780888	0.016994195
53.	Somalia	0.090233	300,000	4366.37487	1.45545829	2881.807414	0.960602471
54.	Fiji	0.075277	800,000	3642.65403	0.455331754	2404.15166	0.300518957
55.	Equatorial Guinea	0.071673	91,140	3468.25647	3.805416359	2289.04927	2.511574797
56.	Comoros	0.068733	40,920	3325.98987	8.128029985	2195.153314	5.36449979

S/N	Country	2014 Cassava output (×10⁹ kg) [b]	2014 National energy consumption (MW.h/Y) [c]	Energy from CPR if 100% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 100% national cassava output was processed (%)	Energy from CPR if 66% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 66% national cassava output was processed (%)
57.	Mali	0.052152	1,400,000	2523.63528	0.180259663	1665.599285	0.118971377
58.	Malaysia	0.051911	131,000,000	2511.97329	0.001917537	1657.902371	0.001265574
59.	Guinea-Bissau	0.045392	31,620	2196.51888	6.946612524	1449.702461	4.584764266
60.	El Salvador	0.036026	5,700,000	1743.29814	0.030584178	1150.576772	0.020185557
61.	French Guiana	0.029906	—	1447.15134	—	955.1198844	—
62.	Timor-Leste	0.029485	125,300	1426.77915	1.138690463	941.674239	0.751535706
63.	Honduras	0.025526	5,300,000	1235.20314	0.02330572	815.2340724	0.015381775
64.	Panama	0.018802	7,800,000	909.82878	0.011664472	600.4869948	0.007698551
65.	Mexico	0.018135	238,000,000	877.55265	0.00036872	579.184749	0.000243355
66.	Guatemala	0.017498	8,915,000	846.72822	0.009497793	558.8406252	0.006268543
67.	Jamaica	0.016549	2,800,000	800.80611	0.028600218	528.5320326	0.018876144
68.	Taiwan, China Rep	0.013017	249,500,000	629.89263	0.000252462	415.7291358	0.000166625
69.	Gambia	0.011555	300,000	559.14645	0.18638215	369.036657	0.123012219
70.	Micronesia (Fed. States)	0.008891	178,000	430.23549	0.241705331	283.9554234	0.159525519
71.	Tonga	0.007862	46,500	380.44218	0.818155226	251.0918388	0.539982449
72.	Suriname	0.007127	1,900,000	344.87553	0.018151344	227.6178498	0.011979887
73.	Guyana	0.006781	800,000	328.13259	0.041016574	216.5675094	0.027070939
74.	Burkina Faso	0.004105	1,200,000	198.64095	0.016553413	131.103027	0.010925252
75.	Cabo Verde	0.003847	300,000	186.15633	0.06205211	122.8631778	0.040954393

S/N	Country	2014 Cassava output (×10⁹ kg) [b]	2014 National energy consumption (MW.h/Y) [c]	Energy from CPR if 100% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 100% national cassava output was processed (%)	Energy from CPR if 66% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 66% national cassava output was processed (%)
76.	French Polynesia	0.003805	700,000	184.12395	0.026303421	121.521807	0.017360258
77.	Trinidad and Tobago	0.003194	9,100,000	154.55766	0.001698436	102.0080556	0.001120968
78.	Brunei Darussalam	0.00306	3,766,000	148.0734	0.003931848	97.728444	0.00259502
79.	Solomon Islands	0.003025	79,050	146.37975	0.185173624	96.610635	0.122214592
80.	Wallis and Futuna Islands	0.001874	—	90.68286	—	59.8506876	—
81.	New Caledonia	0.001777	2,000,000	85.98903	0.004299452	56.7527598	0.002837638
82.	Sao Tome and Principe	0.001349	65,100	65.27811	0.100273594	43.0835526	0.066180572
83.	Guadeloupe	0.001235	—	59.76165	—	39.442689	—
84.	Saint Lucia	0.001233	300,000	59.66487	0.01988829	39.3788142	0.013126271
85.	Dominica	0.001217	90,210	58.89063	0.065281709	38.8678158	0.043085928
86.	Bahamas	0.000938	1,600,000	45.38982	0.002836864	29.9572812	0.00187233
87.	Belize	0.000927	400,000	44.85753	0.011214383	29.6059698	0.007401492
88.	Cook Islands	0.000869	31,620	42.05091	0.13298833	27.7536006	0.087772298
89.	St. Vin./Gren.	0.000721	100,000	34.88919	0.03488919	23.0268654	0.023026865
90.	Barbados	0.000553	900,000	26.75967	0.002973297	17.6613822	0.001962376
91.	Mauritius	0.000466	2,600,000	22.54974	0.000867298	14.8828284	0.000572416

S/N	Country	2014 Cassava output (×10⁹ kg) [b]	2014 National energy consumption (MW.h/Y) [c]	Energy from CPR if 100% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 100% national cassava output was processed (%)	Energy from CPR if 66% of national cassava output was processed (MW.h/Y)	Potential of CPR to provide national energy requirement if 66% national cassava output was processed (%)
92.	Samoa	0.000424	100,000	20.51736	0.02051736	13.5414576	0.013541458
93.	Puerto Rico	0.000377	19,000,000	18.24303	9.60159E-05	12.0403998	6.33705E-05
94.	Mauritania	0.00025	800,000	12.0975	0.001512188	7.98435	0.000998044
95.	Seychelles	0.000232	300,000	11.22648	0.00374216	7.4094768	0.002469826
96.	Grenada	0.000217	200,000	10.50063	0.005250315	6.9304158	0.003465208
97.	Antig./ Barbuda	0.000127	300,000	6.14553	0.00204851	4.0560498	0.001352017
98.	Ame. Samoa	0.000087	100,000	4.20993	0.00420993	2.7785538	0.002778554
99.	Niue	0.000044	3720	2.12916	0.057235484	1.4052456	0.037775419
100.	Réunion	0.000036	—	1.74204	—	1.1497464	—
101.	Cay. Islands	0.000007	600,000	0.33873	0.000056455	0.2235618	3.72603E-05
102.	Maldives	0.000006	300,000	0.29034	0.00009678	0.1916244	6.38748E-05
103.	Singapore	0.000001	47,180,000	0.04839	1.02565E-07	0.0319374	6.76927E-08

[a]Using HHV (heat of combustion) = 55.53 MJ/(kg CH_4) and ϵ (conversion efficiency from thermal energy to electrical energy) = 25%.

[b]Source: [24].

[c]Source: [68, 69].

Table 4. Year 2014 cassava production output of nations, their energy consumption capacity and potential of CPR generated from cassava processing to provide national energy requirements [a]

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5. Applications, utilizations and dividends of biomethane from CPR

The anaerobic digestion of CPR would generate biogas, which could be used as is or upgraded to obtain more efficient biomethane. The energy content of either fuel could be put to various applications and utilities. These include:

- Fuel for stoves in cooking; boiling, frying, roasting, etc.
- Fuel for lamps in lighting; illumination, reading, playing, etc.
- Fuel for transportation; cars, trucks, sea vessels, etc.
- Electrical power in processing operations; drying, grinding, heating, pumping, refrigeration, washing, etc.
- The digester effluent (digestate) could be utilized for soil amendment and/or serve as biofertilizer for enhanced crop production. This was demonstrated to increase potato yield [38].
- Perhaps the critical humane benefits are the reduction of drudgery and burden on the one hand and the improvement of health conditions on the other hand. This is due to reduced time spent on fetching firewood and charcoal for domestic fuel, and the reduced exposure to their combustion products.
    - Women and children may carry on their head 10 kg of firewood for distances up to 8 km, spending 5–6 hours per trip [39]; 2–6 hours per day [40].; or 5 hours per week [38]

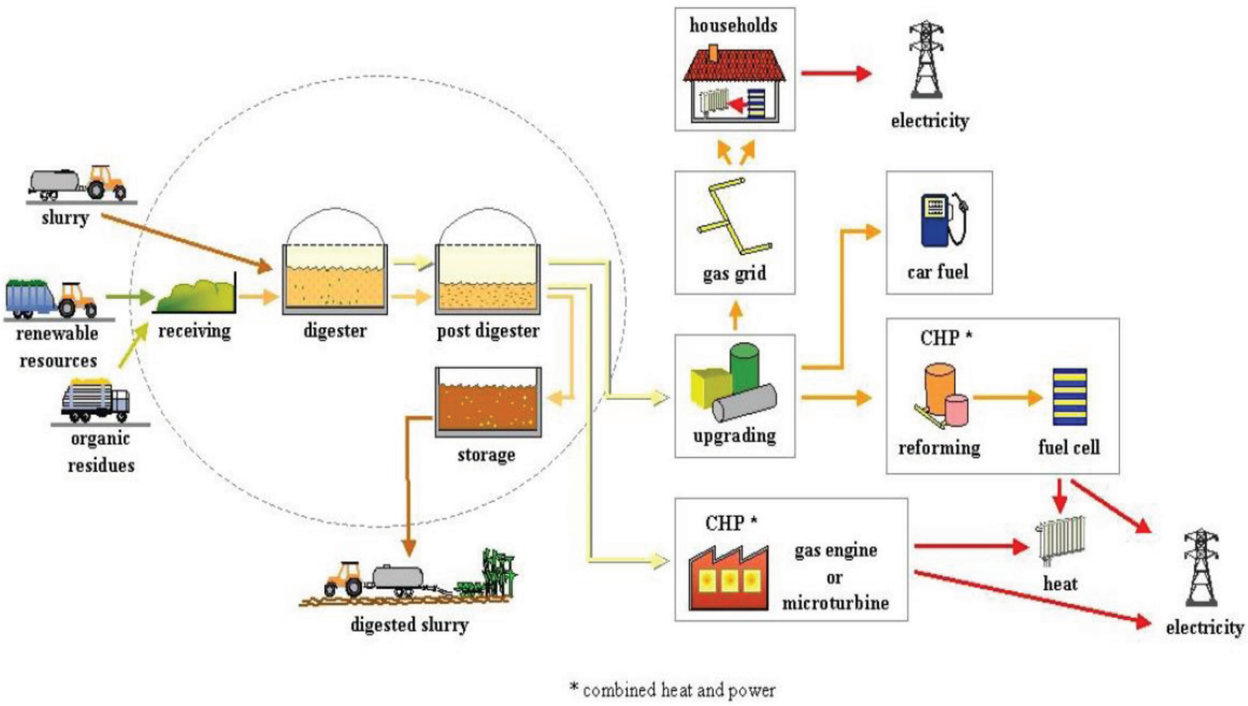

Figure 3. Schematics of biomethane production by anaerobic digestion of renewable feedstocks and pathways of the biomethane utilization. Adopted with permission from Ref. [46].

- Domestic combustion of the firewood releases health-impairing pollutants like carbon monoxide, hydrocarbons, smoke and other particulate matter. These combustion products may cause nausea, sneezing, eye and respiratory irritations [41]; pneumonia, lung cancer, and respiratory infections [42]; and reduced birth weight [43].
- Biomethane utilization reduced firewood consumption by 74% in China [44] and 84% in Sri Lanka [45], thereby minimizing the drudgery, burden, and health hazards associated with use of firewood for domestic energy.

Figure 3 presents pathways of the production and utilization of biomethane from CPR and other renewable feedstocks.

6. Conclusions

Global energy security, sustainability and renewability could be enhanced by harnessing non-food biomass. The work presented in this chapter demonstrated that anaerobic digestion of cassava peeling residue (CPR) generated biomethane that could come to the energy rescue of cassava producing nations. Depending on the specific country and proportion of national cassava output processed, recovered biomethane from CPR could provide up to 7% national energy requirement in Haiti; 8% in Comoros; 10% in Cambodia; 11% in Nigeria; 31% in Rwanda; and 100% in Sierra Leone. The biomethane could be put to various applications and utilities that minimize the drudgery and burden of gathering wood and charcoal for domestic fuel. As additional dividends, use of the biomethane would prevent implications of the combustion products of these solid fuels that degrade air quality and impair human health. The time saved from fetching firewood may be put to economic, educational and social activities. Furthermore, the digester effluent (digestate) could be sold for soil amendment and as organic fertilizer, or applied to agricultural land for increased crop yield. Either way more revenue is generated for economic empowerment. Therefore, anaerobic digestion of CPR would help cassava producing nations to not only mitigate their energy insufficiency, but also address issues such as climate change, environmental degradation, poverty alleviation, rural development, and the sanitation and health hazards associated with the use of wood and charcoal as fuel.

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References

[1] UNDESA: United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2015 Revision, DVD Edition. 2015. http://esa.un.org/unpd/wpp/Download/Standard/Population/

[2] REN21: Renewable Energy Policy Network for the 21st Century. Renewables 2014 Global Status Report. 2014. http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_full%20report_low%20res.pdf

[3] World Bank. Mozambique Agricultural Development Strategy: Stimulating Smallholder Agricultural Growth. Report No. 32416-MZ, World Bank Agriculture, Environment, and Social Development Unit. 2006. http://siteresources.worldbank.org/MOZAMBIQUEEXTN/Resources/Moz_AG_Strategy.pdf

[4] Zvinavashe E, Elbersen HW, Slingerland M, Kolijn S, Sanders JP. Cassava for food and energy: Exploring potential benefits of processing of cassava into cassava flour and bioenergy at farmstead and community levels in rural Mozambique. Biofuels, Bioproducts and Biorefining. 2011;**5**(2):151-164

[5] Lansing S, Bowen H, Gregoire K, Klavon K, Moss A, Eaton A, et al. Methane production for sanitation improvement in Haiti. Biomass and Bioenergy. 2016;**91**:288-295

[6] World Bank. Haiti: Strategy to Alleviate the Pressure of Fuel Demand on National Woodfuel Resources. Energy Sector Management Assistance Program (ESMAP) Technical Paper 112/07. Washington, D.C.: The International Bank for Reconstruction and Development/THE WORLD BANK; 2007 https://www.esmap.org/sites/esmap.org/files/TR_11207_Haiti%20Strategy%20to%20Alleviate%20the%20Pressure%20of%20Fuel%20Demand%20on%20National%20Woodfuel%20Resources_112-07.pdf

[7] Duku MH, Gu S, Hagan EB. A comprehensive review of biomass resources and biofuels potential in Ghana. Renewable and Sustainable Energy Reviews. 2011;**15**(1):404-415

[8] EurObserv'ER. The state of renewable energies in Europe. 16th EurObserv'ER Report. 2016 Edition. 2017. https://www.eurobserv-er.org/

[9] Aso SN. Food engineering stratagem to protect the environment and improve the income opportunities of gari processors. Journal of Nigerian Environmental Society (JNES). 2004;**2**(1):31-36

[10] Aso SN. Synergistic enzymatic hydrolysis of cassava starch and anaerobic digestion of cassava waste. PhD Dissertation. Gainesville, Florida: University of Florida, Department of Agricultural and Biological Engineering; 2013

[11] Ayankunbi MA, Keshinro OO, Egele P. Effects of methods of preparation on the nutrient composition of some cassava products – Garri (Eba), 'Lafun' and 'Fufu'. Food Chemistry. 1991;**41**(3):349-354

[12] Balagopalan C, Padmaja G, Nanda SK, Moorthy SN. Cassava in Food, Feed, and Industry. Boca Raton, Florida: CRC Press, Inc; 1988

[13] Bourdoux P, Seghers P, Mafuta M, Vanderpas J, Vanderpas-Rivera M, Delange F, Ermans AM. Cassava products: HCN content and detoxification processes. In: Delange F, Iteke FB, Ermans AM, editors. Nutritional Factors Involved in the Goitrogenic Action of Cassava. Ottawa, Canada: International Development Research Centre (IDRC) Report No. IDRC–184e, IDRC; 1982. pp. 51-58

[14] Collard P, Levi S. A two-stage fermentation of cassava. *Nature*. 1959;**183**(4661):620-621

[15] Congocookbook.com. Baton de Manioc & Chikwangue. 2013. http://congocookbook.com/staple_dish_recipes/baton_de_manioc_and_chikwangue.html

[16] Dufour DL. "Bitter" cassava: Toxicity and detoxification. In: Ortiz R, Nassar N, editors. Proceedings of First International Meeting on Cassava Breeding, Biotechnology and Ecology. Brasilia: University of Brasilia; 2007. pp. 171-184. http://www.geneconserve.pro.br/site/pags/meeting2/proceedings.pdf#page=171

[17] Hahn SK. An overview of traditional processing and utilization of cassava in Africa. Cassava as livestock feed in Africa: Proceedings of the IITA/ILCA/University of Ibadan Workshop on the Potential Utilization of Cassava as Livestock Feed in Africa, 14-18 November 1988, Ibadan, Nigeria. 1992. pp. 16-27. http://www.fao.org/Wairdocs/ILRI/x5458E/x5458e05.htm

[18] Lancaster PA, Ingram JS, Lim MY, Coursey DG. Traditional cassava–based foods: Survey of processing techniques. Economic Botany. 1982;**36**(1):12-45

[19] Mahungu NM, Yamaguchi Y, Almazan AM, Kahn SK. Reduction of cyanide during processing of cassava into some traditional African foods. Journal of Food and Agriculture. 1987;**1**(1):11-15

[20] Ross J. Attieke, a "new" staple. Minnesota Monthly, Monday 17th September 2012. 2012. http://www.minnesotamonthly.com/media/Blogs/Twin-Cities-Taste/September-2012/Attieke-a-New-Staple/

[21] Seigler DS, Pereira JF. Modernized preparation of casave in the *Ilanos orientales* of Venezuela. Economic Botany. 1981;**35**(3):356-362

[22] Sokari TG. Improving the nutritional quality of Ogi and Gari. In: Applications of Biotechnology in Traditional Fermented Foods. Washington, DC: National Academy Press; 1992. pp. 93-99

[23] FAO: Food and Agriculture Organization of the United Nations. Cassava for Food and Energy Security - Investing in Cassava Research and Development could Boost Yields and Industrial Uses. FAO, Rome: Posted by African Press Organization; 2008. http://appablog.wordpress.com/2008/07/25/cassava-for-food-and-energy-security-investing-in-cassava-research-and-development-could-boost-yields-and-industrial-uses/

[24] FAO: Food and Agriculture Organization of the United Nations. FAOSTAT. Online Statistical Database for Food and Agricultural Commodities Production. 2017. http://www.fao.org/faostat/en/#data/QC/visualize

[25] Nassar N, Ortiz R. Breeding cassava to feed the poor. Scientific American. 2010;**302**(5):78-84. DOI: 10.1038/scientificamerican0510-78 http://stopogm.net/sites/stopogm.net/files/webfm/plataforma/breedingcassava.pdf

[26] Donovan C, Haggblade S, Salegua VA, Cuambe C, Mudema J, Tomo A. Cassava commercialization in Mozambique (Working Paper No. 120). Michigan State University, Department of Agricultural, Food, and Resource Economics. 2011; http://ageconsearch.umn.edu/bitstream/120744/2/idwp120.pdf

[27] Koch BM, Sibbesen O, Swain E, Kahn RA, Liangcheng D, Bak S, Halkier BA, Moller BL. Possible use of a biotechnological approach to optimize and regulate the content and distribution of cyanogenic glucosides in cassava to increase food safety. Acta Horticulturae. 1994;(375):45-60. DOI: 10.17660/ActaHortic.1994.375.2

[28] Jansson C, Westerbergh A, Zhang J, Hu X, Sun C. Cassava, a potential biofuel crop in (the) People's republic of China. Applied Energy. 2009;**86**(S1):S95-S99

[29] CGIAR: Consultative Group on International Agricultural Research. Report on the Inter-Centre Review of Root and Tuber Crops Research in the CGIAR. Rome: FAO; 1997 http://www.fao.org/Wairdocs/TAC/X5791E/x5791e00.htm

[30] Rogers DJ. Some botanical and ethnological considerations of *Manihot esculenta*. Economic Botany. 1965;**19**(4):369-377

[31] El-Sharkawy MA, De Tafur SM, Cadavid LF. Potential photosynthesis of cassava as affected by growth conditions. Crop Science. 1992;**32**(6):1336-1342

[32] Wang, W. (2007). Cassava production for industrial utilization in China – Present and future perspectives. In: Howeler, RH, editor. Cassava Research and Development in Asia: Exploring New Opportunities for an Ancient Crop. Proceedings of the Seventh Regional Workshop, Bangkok, Thailand. October 28–November 1, 2002. pp. 33-38

[33] Sigarchian SG, Paleta R, Malmquist A, Pina A. Feasibility study of using a biogas engine as backup in a decentralized hybrid (PV/wind/battery) power generation system–case study Kenya. Energy. 2015;**90**(Part 2):1830-1841

[34] Pierie F, van Someren CEJ, Benders RMJ, Bekkering J, van Gemert WT, Moll HC. Environmental and energy system analysis of bio-methane production pathways: A comparison between feedstocks and process optimizations. Applied Energy. 2015; **160**:456-466

[35] Lema JM, Omil F. Anaerobic treatment: A key technology for a sustainable management of wastes in Europe. Water Science and Technology. 2001;**44**(8):133-140

[36] Lettinga G. Digestion and degradation, air for life. Water Science and Technology. 2001;**44**(8):157-176

[37] Sovacool BK, Dworkin MH. Energy justice: Conceptual insights and practical applications. Applied Energy. 2015;**142**:435-444

[38] Garfi M, Ferrer-Marti L, Velo E, Ferrer I. Evaluating benefits of low-cost household digesters for rural Andean communities. Renewable and Sustainable Energy Reviews. 2012;**16**(1):575-581

[39] Masekoameng KE, Simalenga TE, Saidi T. Household energy needs and utilization patterns in the Giyani rural communities of Limpopo Province, South Africa. Journal of Energy in Southern Africa. 2005;**16**(3):4-9

[40] DFID: Department for International Development. Energy for the Poor: Underpinning the Millennium Development Goals. 2002. https://www.ecn.nl/fileadmin/ecn/units/bs/JEPP/energyforthepoor.pdf.

[41] Oguntoke O, Opeolu BO, Babatunde N. Indoor air pollution and health risks among rural dwellers in Odeda area, south-western Nigeria. Ethiopian Journal of Environmental Studies and Management. 2010;**3**(2):39-46

[42] Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S, Murray CJ, Comparative Risk Assessment Collaborating Group. Selected major risk factors and global and regional burden of disease. The Lancet. 2002;**360**(9343):1347-1360. DOI: 10.1016/S0140-6736(02)11403-6

[43] Boy E, Bruce N, Delgado H. Birth weight and exposure to kitchen wood smoke during pregnancy in rural Guatemala. Environmental Health Perspectives. 2002;**110**(1):109-114

[44] Remais J, Chen L, Seto E. Leveraging rural energy investment for parasitic disease control: Schistosome ova inactivation and energy co-benefits of anaerobic digesters in rural China. PLoS One. 2009;**4**(3):e4856

[45] De Alwis A. Biogas–a review of Sri Lanka's performance with a renewable energy technology. Energy for Sustainable Development. 2002;**6**(1):30-37

[46] Plochl M, Heiermann M. Biogas farming in central and northern Europe: A strategy for developing countries? Invited overview. Agricultural Engineering International. 2006;**8**(8):1-15

[47] Cuzin N, Farinet JL, Segretain C, Labat M. Methanogenic fermentation of cassava peel using a pilot plug flow digester. Bioresource Technology. 1992;**41**(3):259-264

[48] Jekayinfa SO, Scholz V. Laboratory scale preparation of biogas from cassava tubers, cassava peels, and palm kernel oil residues. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2013;**35**(21):2022-2032. DOI: 10.1080/15567036.2010.532190

[49] Ukpai PA, Nnabuchi MN. Comparative study of biogas production from cow dung, cowpea and cassava peeling using 45 litres biogas digester. Advances in Applied Science Research. 2012;**3**(3):1864-1869

[50] Ofoefule AU, Uzodinma EO. Biogas production from blends of cassava (*Manihot utilissima*) peels with some animal wastes. International Journal of Physical Sciences. 2009;**4**(7):398-402

[51] Colin X, Farinet JL, Rojas O, Alazard D. Anaerobic treatment of cassava starch extraction wastewater using a horizontal flow filter with bamboo as support. Bioresource Technology. 2007;**98**(8):1602-1607

[52] Manilal VB, Narayanan CS, Balagopalan C. Anaerobic digestion of cassava starch factory effluent. World Journal of Microbiology and Biotechnology. 1990;**6**(2):149-154

[53] Sun L, Wan S, Yu Z, Wang Y, Wang S. Anaerobic biological treatment of high strength cassava starch wastewater in a new type up-flow multistage anaerobic reactor. Bioresource Technology. 2012;**104**:280-288

[54] Zhu W, Lestander TA, Örberg H, Wei M, Hedman B, Ren J, et al. Cassava stems: A new resource to increase food and fuel production. Global Change Biology (GCB) Bioenergy. 2015;**7**(1):72-83

[55] Rajbhandari BK, Annachhatre AP. Anaerobic ponds treatment of starch wastewater: Case study in Thailand. Bioresource Technology. 2004;**95**:135-143

[56] Wang W, Xie L, Chen J, Luo G, Zhou Q. Biohydrogen and methane production by co-digestion of cassava stillage and excess sludge under thermophilic condition. Bioresource Technology. 2011;**102**(4):3833-3839

[57] Zhang Q, He J, Tian M, Mao Z, Tang L, Zhang J, Zhang H. Enhancement of methane production from cassava residues by biological pretreatment using a constructed microbial consortium. Bioresource Technology. 2011;**102**(19):8899-8906

[58] Luo G, Xie L, Zou Z, Wang W, Zhou Q, Shim H. Anaerobic treatment of cassava stillage for hydrogen and methane production in continuously stirred tank reactor (CSTR) under high organic loading rate (OLR). International Journal of Hydrogen Energy. 2010;**35**:11733-11737

[59] Zhang Q, Tang L, Zhang J, Mao Z, Jiang L. Optimization of thermal-dilute sulfuric acid pretreatment for enhancement of methane production from cassava residues. Bioresource Technology. 2011;**102**(4):3958-3965

[60] Luo G, Xie L, Zhou Q. Enhanced treatment efficiency of an anaerobic sequencing batch reactor (ASBR) for cassava stillage with high solids content. Journal of Bioscience and Bioengineering. 2009;**107**(6):641-645

[61] Anunputtikul W, Rodtong S. Laboratory scale experiments for biogas production from cassava tubers. In: Proceedings of the Joint International Conference on "Sustainable Energy and Environment (SEE), Hua Hin: Thailand; 2004. pp. 1-3

[62] Paixão MA, Tavares CR, Bergamasco R, Bonifácio AL, Costa RT. Anaerobic digestion from residue of industrial cassava industrialization with acidogenic and methanogenic physical separation phases. Applied Biochemistry and Biotechnology. 2000;**84-86**(1-9):809-819

[63] Cooke RD, de la Cruz EM. The changes in cyanide content of cassava (*Manihot esculenta Crantz*) tissues during plant development. Journal of the Science of Food and Agriculture. 1982;**33**(3):269-275

[64] Dufour DL. Cyanide content of cassava (*Manihot esculenta*, Euphorbiaceae) cultivars used by Tukanoan Indians in Northwest Amazonia. Economic Botany. 1988;**42**(2):255-266

[65] Gomez G, Valdivieso M. The effect of variety and plant age on cyanide content, chemical composition and quality of cassava roots. Nutrition Reports International. 1983; **27**(4):857-865

[66] Gomez G, Valdivieso M, Noma AT. The influence of cultivar and plant age on the chemical composition of field-grown cassava leaves and roots. Qualitas Plantarum - Plant Foods for Human Nutrition. 1985;**35**(2):109-119

[67] Tonukari NJ. Cassava and the future of starch. Electronic Journal of Biotechnology. 2004;**7**(1):5-8

[68] CIA: Central Intelligence Agency. The World Factbook. Country Comparison: Electricity-Consumption; 2017. https://www.cia.gov/library/publications/the-world-factbook/rankorder/2233rank.html

[69] Wikipedia. List of Countries by Electricity Consumption. 2017. https://en.wikipedia.org/wiki/List_of_countries_by_electricity_consumption